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A COMPARATIVE STUDY OF SHALE CLASSIFICATION TESTS AND SYSTEMS

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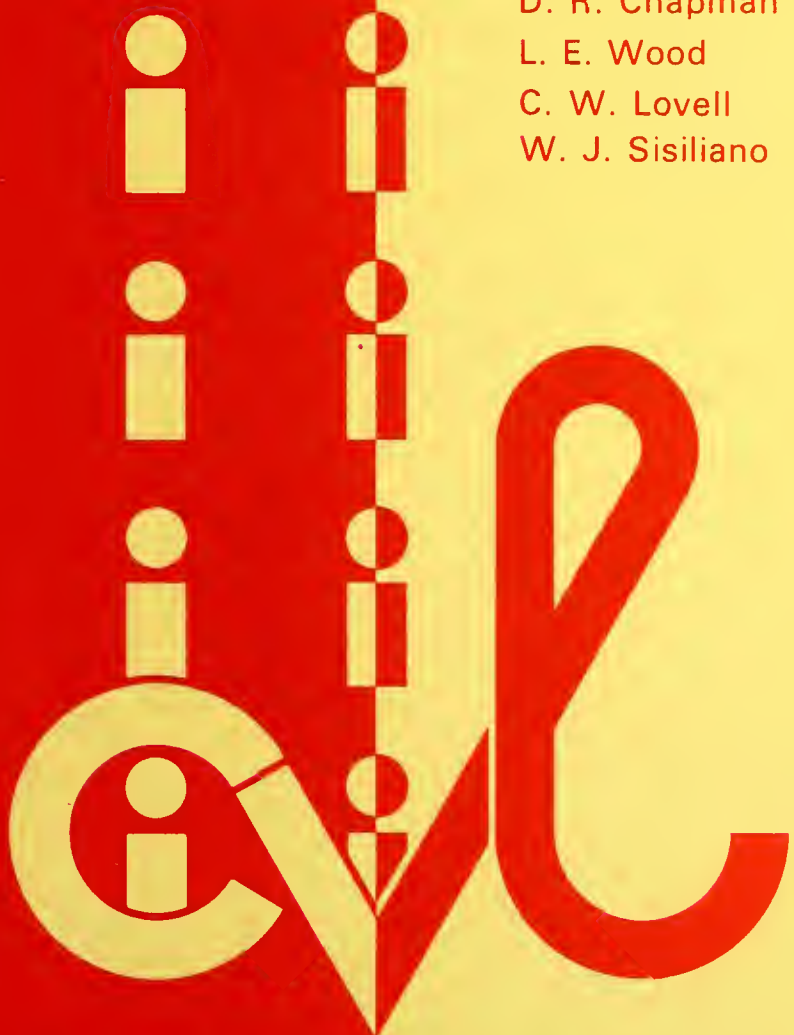

PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Technical Paper

A COMPARATIVE STUDY OF SHALE CLASSIFICATION TESTS AND SYSTEMS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

March 16, 1976

File: 6-6-12

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-5L

Attached is a Technical Paper titled "A Comparative Study of Shale Classification Tests and Systems". The paper is from the Interim Report titled "Shale Classification Tests and Systems: A Comparative Study" on the HPR Part II Research Study "Design and Construction Guidelines for Shale Embankments". This Report has been reviewed and accepted by all sponsors of the research.

The paper is co-authored by Messrs. D. R. Chapman, L. E. Wood, C. W. Lovell and W. J. Sisiliano, the principal investigators on the Study. It was presented in November 1975 to the Annual Meeting of the Association of Engineering Geologists and is now being submitted for publication in their Journal.

The paper is submitted to the Board for approval of publication. It will be forwarded to ISHC and FHWA for review and comment and as information in accordance with current publications procedures.

Respectfully submitted,

Harold L. Michael
Associate Director

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16. Abstract

The abundance of shale rock necessitates its economical and efficient use in compacted embankments. Differing shale durabilities require a variety of design parameters and construction techniques. Classification systems for shales are available, and are helpful, but most have not been definitively correlated with field performance of compacted shales.

Simple laboratory tests were selected from several existing classification systems, and performed on six Indiana shales. Tests included: Slake Durability, slaking tests with different slaking fluids, Atterberg limits, Los Angeles Abrasion, Schmidt Hammer hardness, and the Washington Degradation test. Also included was a study of sample preparation effects on Atterberg limits results. The shales were then classified by each system, and the descriptive categories for the various systems were compared. Regression analysis was used to examine statistical relationships among results from different tests. X-ray diffraction patterns and some soil chemistry procedures were used to identify constituent minerals and their relative percentages.

Tests expected to be particularly useful in shale classification include Slake Durability and two simple slaking procedures. Tests designed to evaluate mineral aggregates for pavements were generally too severe for the softer shales which are most prevalent in Indiana.

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A COMPARATIVE STUDY OF SHALE CLASSIFICATION TESTS AND SYSTEMS

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Purdue University
West Lafayette, Indiana
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A COMPARATIVE STUDY OF SHALE CLASSIFICATION TESTS AND SYSTEMS

ABSTRACT

The abundance of shale rock necessitates its economical and efficient use in compacted embankments. Differing shale durabilities require a variety of design parameters and construction techniques. Classification systems for shales are available, and are helpful, but most have not been definitively correlated with field performance of compacted shales.

Simple laboratory tests were selected from several existing classification systems, and performed on six Indiana shales. Tests included: Slake Durability, slaking tests with different slaking fluids, Atterberg limits, Los Angeles Abrasion, Schmidt Hammer hardness, and the Washington Degradation test. Also included was a study of sample preparation effects on Atterberg limits results. The shales were then classified by each system, and the descriptive categories for the various systems were compared.

Tests found to be particularly useful in shale classification include Slake Durability and two simple slaking procedures. Tests designed to evaluate mineral aggregates for pavements were generally too severe for the softer shales which are most prevalent in Indiana.

The major deficiency in the present State-of-the-Art seems to be the lack of correlation of classification indices with field performance. Instrumentation of shale embankments is necessary to provide the information to correct this deficiency.

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INTRODUCTION

Shale is one of the most commonly occurring soil or rock materials on the earth's surface. The term "shale" has been applied to many classes of materials which can be generally described as fine-grained, clastic sedimentary rocks. The definition selected as most appropriate is "an argillaceous rock possessing lamination or fissility." The non-fissile equivalents are then termed mudstone, siltstone, or claystone, depending on their composition. This definition follows Underwood (1967).

Shales are problem materials in several phases of geotechnical engineering because of their composition and durability. Shale is the boundary material between "soil" and "rock," and for some applications, it needs different treatment from either soil or rock. This study was conducted as part of a research project dealing with the use of shales for embankment materials.

Shale properties pertinent to embankment construction include its degradation and slaking behavior. Degradation is defined as reduction in aggregation size due to construction operations, and slaking as decomposition due to subsequent weathering within the embankment. Because shales are widely variable due to differences in composition and cementation, their durabilities and degradation characteristics are thus variable also.

Variations in shale properties give rise to a need for special guidelines for safe, economical use as construction materials. The guidelines must be formulated upon the basis of a sound, concise classification system which groups shales by expected construction and long-

term behavior. Because of these factors, a number of classification systems for argillaceous rocks have been developed.

These systems fall into 3 basic categories:

1. General systems developed for use by geologists, consisting primarily of genetic, qualitative information.
2. General systems developed for use by engineers, emphasizing quantitative information obtained from tests performed to evaluate properties of the shales.
3. Systems developed by a given agency for its own purposes and use. These can fall into either of the other two categories, or contain elements of both. This type of system may work well for a given locality and be virtually inapplicable elsewhere.

This study dealt primarily with the engineer's type of classification system, because quantification of the classification categories was felt to be essential. This approach involves the use of existing tests and classification procedures, or the development of new ones. It was decided to study the interrelationships of several existing systems as they are used to classify a given group of shales. The ultimate goal is a simpler, more rational, and more universal classification system.

Philosophy of Classifying Engineering Materials

The variability, and the wide occurrence of a material such as shale, make classification and evaluation of its probable behavior an important stage in the design and construction process. A number of

classification systems have been developed to deal with the problems caused by the character of shale.

Classification, if well done, in a rational manner, can improve the likelihood that an expedient design will be made. This presupposes, of course, that an adequate classification system is already at the disposal of someone qualified to use it. The very number of classification systems in existence give evidence that there is no one system which is widely accepted as satisfactory.

The characteristics of individual tests used have great bearing on the effectiveness of a system. Test characteristics deemed important by Aufmuth (1974) and Franklin (1970) include simplicity, economy, reproducibility of results, ability of the test to accurately differentiate samples of varying behavior, and applicability of the results to engineering design.

Classification Systems and Tests

To meet the needs described previously, classification systems have been proposed by several investigators (Deo, 1972; Gamble, 1971; Morgenstern and Eigenbrod, 1974; Reidenouer, Geiger, and Howe, 1974; and Underwood, 1967). Because the various researchers had differing objectives, there is considerable variation in the types of tests investigated, and also in the types and ages of geologic materials which were tested. The classification systems were reviewed amply by Wood and Deo (1975).

One of the major aspects of this part of the total research effort was the further investigation of the Slake Durability Test. Rock materials

in nature constantly undergo degradation due to weathering, some of which takes place over long periods of time, and some which takes place at a sufficiently rapid rate to be of significance within the life of the structure. Franklin and Chandra (1972) sought to develop a test which could predict the expected degree of "short-term" weathering. They defined "slake durability" as the "... capacity of the rock to resist changes, wear, or breakdown with time when subjected to the slaking action of water, as exhibited by breaking or disintegrating into smaller pieces. It is essentially a physical process, and broken particles do not lose their identity, but still resemble the parent rock material". They developed the Slake durability test, which gives a numerical result I_d, and which can be used to describe durability.

Deo (1972) has given an excellent review of slaking tests and general behavior of shales subjected to moisture. Moriwaki (1975) performed a detailed study of the actual slaking mechanisms. The mechanisms which govern the disintegration of shales are complicated and hard to identify, especially when mechanisms interact. Thus, for the engineer's purpose, the simpler tests seem to have more promise. Following up Deo's work (1972), the Indiana State Highway Commission has developed a quantification for the slaking test as follows. After each soaking cycle, the material is washed over a #10 sieve, and retained material is subjected to additional cycles. The Slake Index of a shale is defined, after 5 cycles as:

$$SI = \frac{\text{Total wt. of shale lost through \#10 sieve x 100}}{\text{Total original wt. of shale}}$$

The #10 sieve was selected to permit a comparison between this test and the Slake Durability Test, which employs a drum constructed from #10 mesh (Indiana State Highway Commission, 1974).

From the references cited, it can be seen that the problems associated with shale classification and utilization are many and varied. Classification systems already in use are numerous, and diverse in their scope and application. It is probable that existing systems can be modified and combined to identify a more applicable combination of tests and classification crieteria.

RESEARCH APPROACH AND LABORATORY TESTING PROGRAM

Research Approach

Varying shale properties, and their effect on embankment performance, make it desirable to first classify shales by means of their differing expected behaviors. Some shales degrade readily in the process of excavation, hauling, and placement. Others seem more durable as they remain in large chunks during construction, but may cause settlement due to slaking later if placed so that there are relatively large voids present. A third class of shales has seemed to perform satisfactorily as rockfill. It is obvious that failure to correctly predict these differences can be unsafe on one hand, and overly conservative on the other. It is necessary to have some means of accurately predicting shale behavior so the proper decisions can be made at the time of construction.

The number of existing classification systems, and the fact that in few if any cases have the same shales been tested and classified in more than one system, led to the decision to make a comparison between classification systems. The real objective of the testing program was to identify simple, economical tests to be used in classifying shale,

and to verify, modify, and/or supplement the classification system proposed by Deo (1972) shown in figure 1.

Tests from several classification systems were chosen to accomplish this objective. These tests were selected primarily on the basis of simplicity since this is one of the requirements for a good classification test. Very little attention was paid to a study of slaking mechanisms by laboratory testing because of the complicated test procedures required

The systems chosen for investigation were Deo's (1972) "Classification for Shales for Embankment Construction", "Durability-Plasticity Classification of Shales and Other Argillaceous Rocks," by Gamble (1971); a procedure from Pennsylvania Department of Transportation (1974) "Shale Suitability - Phase II"; a portion of "Classification of Argillaceous Soils and Rocks," by Morgenstern and Eigenbrod (1974); and a portion of a study by Saltzman (1975) which quantifies rock properties for riprap.

From the results of the study, the ability of certain tests to predict parameters from other tests was to be assessed. As various agencies use some of the procedures and thereby enlarge the data base, the necessary foundation for statistical verification of such relationships will be laid. The ultimate goal is to use the results of one or more simple tests at the time of subsurface investigation to reasonably predict the in-service behavior of any shale strata encountered.

Laboratory Testing Program

The tests involved in the systems selected for study were as follows:

1. Deo's (1972) "Classification of Shales for Embankment Construction"

The method employs a simple 5-cycle slaking test, hereafter referred to as the Slake Index test; Slake Durability tests on dry and soaked samples; and a Modified Soundness test.

2. J. C. Gamble's (1971) "Durability-Plasticity Classification of Shales and Other Argillaceous Rocks". Atterberg limits tests and a 2-cycle Slake Durability test on dry samples form the basis for this method, given as figure 2.
3. Morgenstern and Eigenbroad's (1974) "Classification of Argillaceous Soils and Rocks". Only a portion of the system was selected, because it was felt that the remaining tests were too time-consuming for the intended purpose of this study. The selected portion includes Atterberg limits tests and a simple Rate of Slaking test. Their analysis is carried out by means on the charts shown in figure 3.
4. Pennsylvania Department of Highways "Shale Suitability-Phase II, Final Report" (1974). A simple visual field examination, and the Washington Degradation test were selected from this method for correlation with other systems.
5. Saltzman's "Rock Quality Determination for Large-Size Stone Used in Protective Blankets" (1975). This classification method, recently developed at Purdue University, was included in order to provide more information about the properties of the rocks used in the research. Tests included the Schmidt Rebound Hammer hardness, Los Angeles Abrasion, and Ultrasonic Cavitation.

Also included in the testing program was another soaking test using ethylene glycol as the slaking fluid. Data from extensive tests on

the shales used in the project were available from the Division of Materials and Tests of the Indiana State Highway Commission, who made samples available in large quantities for testing.

Procedures not commonly known include the Rate of Slaking test and the Ultrasonic Cavitation test. The cavitation test will not be described as it was not found to be useful for shale classification. The procedure for the Rate of Slaking test is summarized below.

Irregular lumps of shale less than 1 inch in size were selected and dried to constant weight at 105°C. The dry weight of the material was around 20 grams. The material was immersed as shown in figure 4. After 2 hours, the excess water, was allowed to drip off, and the final water content was determined (Eigenbrod, 1972).

From this, the change in Liquidity Index is calculated from the following relationships:

$$I_L = \frac{w - w_p}{w_L - w_p} = \frac{w - w_p}{I_p}$$

and $$\Delta I_L = I_{L_f} - I_{L_o}$$

where w = natural moisture content

w_p = plastic limit

w_L = liquid limit

I_p = plasticity index

I_{L_o} = liquidity index (original)

I_{L_f} = liquidity index (final)

Based on the value of ΔI_L, the shale is classified as slow, fast, or very fast slaking.

Procedures for the other tests are amply covered in the referenced publications and by Chapman (1975).

Early in the research, the values obtained for Atterberg limits tests were placed in question because of the resistance of some of the shales to mechanical breakdown. Consequently, methods proposed by Townsend and Banks (1974) involving greater energy input were employed in sample preparation. Values from these tests are herein reported.

RESULTS AND CLASSIFICATION

The shales were classified according to each of the selected systems. The tests yielding results deemed most pertinent to classifying shales for embankment construction were then recommended for use.

Deo's Classification System

The tests included in this system are slake index; slake durability, 200 and 500 revolutions, on dry and soaked samples; and the modified soundness test. The classification flow chart for the system is given in figure 1.

Slake Index Test

This test, time consuming and tedius, gave results ranging approximately from zero to nearly one hundred, as may be seen in table 1. Low values indicate the more competent materials. The test results are of only qualitative value at this time, because no known relationship exists between slake index and field performance.

Slake Durability Test

The slake durability test, combining slaking with mechanical agitation for a quickly obtainable index, shows favorable materials by high values of the index. Results for the test, ranging from 7.7 to 99.7 are shown in table 1. The results of the "soaked" tests are generally lower than for the "dry" tests at both 200 and 500 revolution effort levels. The 2-cycle, 200 revolution dry test result is sometimes higher and sometimes lower than the 200 revolution soaked test result. This is thought to be due to geologic variability within each shale, because at times, greatly differing results were obtained. Shale #4, for example, contained plant fragments and some concretions in different portions of the sample, the fragments giving rise to low values, and the concretions to abnormally high values.

In addition to the numerical result for the slake durability test, a post-test material description may be helpful in relating test results to field behavior for any given shale. Samples could be photographed, and a copy of the photo filed with the laboratory report, or standard verbal descriptions could be noted on a data sheet. A possible means of implementing the matter is given below.

Since some shales break into small fragments readily, and yet give high slake durability index values, the material should be described by one of the following categories:

Type I - pieces remain virtually unchanged.

Type II - retained material consists of large and small fragments.

Type III - retained material is exclusively small fragments.

Photos representing the 3 types are shown in figure 5. Types are

numbered in general order of decreasing index values, although Type III could conceivably have a higher index value than Type II, depending on the material.

Modified Soundness Test

This test, which is a modification of the conventional Sodium Sulfate Soundness Test, was found to be quite severe for softer shales, and to have little effect on the very hard ones. Four of the six shales gave values of zero, and the other two gave values greater than 99, as shown in table 1. This evident lack of resolution is a disadvantage of the test, rendering it nearly inapplicable in general classification of shales. The Indiana State Highway Commission is currently using the Deo group of tests for shale classifications, with the modified soundness test supposedly the most severe.

Table 2 depicts the six shales used in the study when they are classified according to Deo's system (1972). Of the 4 "soil-like" shales, shales #1 and #5 would definitely be weak construction materials, and would probably compact readily. Shale #4, where the plant fragments are absent is somewhat hard, as is shale #3. However, the deleterious effects of water on these shales, as reflected by all test results, indicates that they should be thoroughly degraded and compacted to insure that large voids are not left in the embankment, which would allow slaking and probably excessive settlement. The "rock-like" shales, although hard and durable when fresh, may or may not be expected to slake with resulting problems during the life of an embankment. It is not possible to speculate further at this time, since field performance of such shales has not been observed. A rockfill embankment has been

constructed from shale #2, and should provide a means of answering the question left unanswered here, as the embankment is observed over a period of years.

Gamble's Classification System

The tests involved in this system are both fairly simple and quick to perform. They are Atterberg limits and the slake durability test which $(I_d)_{d,200,2nd\ cycle}$ is determined.

Slake Durability Test

The results for this test were expedient to obtain, requiring only subjection of material retained in the drum from a 200 revolution, "dry" test to a second cycle of slaking in the machine. As expected, the results are lower than those obtained for the first cycle although not greatly so for the "rock-like" shales. The results are presented in table 3. A problem noted by Gamble (1971), not encountered in this research, was the formation of "mudballs" with montmorillonite materials, giving apparently high results for I_d. This phenomenon should be carefully noted if it occurs in the use of this test, as it causes errors on the unconservative side.

Atterberg Limits

The results of the Atterberg limits tests are given in table 3. The Atterberg limits for Gamble's classification were obtained using ASTM D421-58. The silty nature of the shales can be recognized from the low plasticity indices.

The limits for shale #2 are not representative, as the material was prepared differently. Because of its high durability and difficulty in preparation of samples, the shale was subjected to a high temperature ($800^{o}F$) to burn off organic material. This certainly resulted in damage to the clay minerals, and altered the plasticity.

Classification

To classify a material by Gamble's system, the slake durability index and plasticity index are plotted on figure 2. For example, shale #5 is a low durability-medium plasticity mudstone, since it is somewhat non-fissile. Classifications for all six shales are given in table 2. Classified by Gamble's system, the "rock-like" shales from Deo's classification both have "very high" durability and "low" plasticity. The "soil-like" shales all exhibit "medium" plasticity, with durabilities ranging from "very low" to "medium". It is likely that most or all shales in Indiana will exhibit plasticity indices in the low to medium range, because of the silty nature of the shale materials in general.

No recommendations are made by Gamble as to which classifications should be treated as soil fill, rockfill, etc. Again, no definitive recommendation can be made because correlation to monitored field performance is not available. However, based on Deo's guidelines and the data available from the Indiana State Highway Commission, the author would recommend careful degradation and compaction of any shale with $(I_d)_{s.200,2nd\ cycle}$ values less than 70. The number might be higher, depending on what is shown by embankments built of shale, but it is not expected to be lower.

Morgenstern and Eigenbrod's Classification System

This classification scheme involved standard compression testing and a tedious slaking procedure, the "Quantitative Slaking Test," as well as "Rate of Slaking" and Atterberg limits. However, due to the objective of this research to obtain simple, economical tests for classification, only the Rate of Slaking and the Atterberg limits were used. Morgenstern and Eigenbrod found that the maximum water content reached by the shale during the Quantitative Slaking Test could be predicted from the liquid limit of the material.

Rate of Slaking Test

The Rate of Slaking test is very simple to perform and requires only a beaker, a funnel, and filter paper. Due to the simplicity of the test and the seeming uncertainty of letting all excess water drip from the shale so that an accurate final moisture content could be obtained, difficulty in obtaining respectable results was anticipated. This was not found to be the case, and the results of test repetitions were quite uniform. Results shown in table 4 are averages of six trials.

The only result which does not properly describe behavior is that for shale #6, which though "rock-like" according to Deo, and of "very high" durability according to Gamble, had a comparatively high in-situ moisture content and high values of ΔI_L and Δw, changes in liquidity index and water content during the test, respectively. Otherwise, the shales showed increasing values of ΔI_L, from strongest to weakest shale as ranked by other tests. High values of Δw and ΔI_L indicate materials which have greater susceptibility to water, and therefore can be expected to slake.

Atterberg Limits

The Atterberg limits for this classification were obtained using ASTM D421-58, and are the same as the results used in Gamble's classification. The results are repeated for convenience is table 4.

Classification

To classify materials by this method, the assumption that the liquid limit predicts maximum slaking water content is used, in conjunction with values of Δw and ΔI_L from the Rate of Slaking Test. Thus, all materials tested are ranked as "low" slaking by amount, as shown in table 2. Classification criteria showed materials ranging from "slow" to "very fast" in rate of slaking. As mentioned before, the results for Shale #6 is not indicative of present behavior and durability. However, the absorptive tendency of this material may indicate that weathering could occur rapidly with moisture changes. Due to this uncertainty, this material should not be employed as rockfill in any important embankment until more was known about its potential in-service behavior.

Other Tests

Saltzman's criteria, established to evaluate rock for riprap material, were found to be too severe for nearly all of the shales tested, and thus were not recommended for shale classification. This was also true of the Washington Degradation test, which was judged not to be of use for Indiana shales in general, although was very successful in classifying the more indurated shales of Pennsylvania (1974).

The ethylene glycol test is designed to cause disintegration of montmorillonitic materials by expansion (Handbook of Concrete and Cement, 1969). For the shales tested, it was much less severe than water as no montmorillonite was present. The test is not recommended, for use with non-expansive materials.

The procedures for the Atterberg limits preparation effects study were taken from Townsend and Banks (1974), and are referred to as "air-dried," and "blenderized". Shales #2 and #6 were excluded from the study because they were essentially rocks and reduction to ultimate particle size was not feasible.

The results of the Atterberg limits tests for the 4 shales which could be subjected to the recommended treatments are given in table 5.

It can be seen that generally, the "air dried" and "blenderized" techniques produce greater indices of plasticity than the ASTM D421-58 method, although there are some slight deviations from this trend. The increase in plastic limit is generally 1 to 2 percent, and that in the liquid limit on the order of several percent. Although the magnitudes of the differences are not as dramatic as those reported by Townsend and Banks (1974) for "clay shales", a significant trend can be seen. In almost all cases, samples that were prepared using a food blender gave higher values of plasticity. The differences can be great enough to change the AASHTO classification of the material from A-6 to A-7-6.

General Discussion

Since the shales in Indiana are predominatly of the softer type, tests which provide a spread of values for such materials should be identified for further investigation. Tests in this category include slake index, slake durability, and rate of slaking. The slake index test is probably less accurate than the others in predicting probable behavior of shales, but can be very useful in quickly identifying a very poor material, i.e., any material which slakes significantly on the first cycle will obviously be severely affected by the other tests.

The classification systems applicable to shale classification are compared for the six shales tested in table 2. Shales classified soil-like by Deo (1972), rank low in durability and medium in plasticity on Gamble's scale (1974). Rock-like shales are very high in durability and low in plasticity. Soil-like shales range from slow to very fast in the Rate of Slaking test, and rock-like shales from slow to fast. All rank low in amount of slaking, as predicted by the liquid limit.

There should be a careful program involving the observation of performance of shales placed as embankment material in conjunction with the application of any classification system. At this point in time, the major deficiency with all of the classification systems is the lack of correlation between classification test values and design and construction standards and specifications.

CONCLUSIONS AND RECOMMENDATIONS

The statements made in this section apply specifically to the use of shales in compacted embankments, and are based upon the testing of only six shales, all from Indiana.

1. Tests which are particularly useful in classifying shales are the: Slake Index, Slake Durability, and Rate of Slaking.

2. Valuable additional information can be obtained from the Slake Durability test by a second cycle of slaking and agitation, as recommended by Gamble (1971), and endorsed by Franklin and Chandra (1972).

3. The Atterberg limits of shales are a function of the energy input during preparation. For most shales it is advisable to use a preparation procedure which involves more energy input than does the conventional ASTM D421-58. Possibilities for such a procedure include the "air dried" and "blenderized" procedures recommended by Townsend and Banks (1974), or other combinations of cyclic air drying and slaking in conjunction with mechanical grinding or pulverization.

4. Information gained from this study does not warrant proposing a new shale classification system. However, general testing guidelines can be proposed as follows. The Slake Index test should be run first. Immediate response in this test is sufficient to classify the shale as definitely "soil-like." If little or no slaking occurs, the shale should be subjected to Slake Durability and Rate of Slaking tests. Low values of Slake Durability Index and high values of change in water content during the Rate of Slaking test indicate poorer materials which should be treated like soils. Field performance of shales must be compared with these test results before quantitative design and construction guidelines can be formulated.

5. Predictions of how thoroughly to degrade and compact shales in the field can be accomplished from classification test values, but only after considerable monitoring of actual embankment performance.

Data for more shales are needed before definitive statements can be made concerning a classification system. Therefore, it is recommended that Slake Index, Slake Durability, and Rate of Slaking test values be accumulated for all embankment shales, and correlated among themselves and with classification indices, compaction, and California Bearing Ratio data.

Extensive study of the behavior of shales placed in instrumented embankments is needed. Excessive settlement is a primary indicator of inadequate shale placement, and can be monitored with settlement plates. Full profile settlement gages as described by Dunnicliff (1971) could also be used to advantage in assessing the distribution of settlements within the embankments. Slope indicators and piezometers should also be installed for additional warning of high shear stresses and any trending toward a slope failure.

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The work reported herein is covered in greater detail in the Purdue MSCE Thesis by Mr. David Chapman entitled "Shale Classification Tests and Systems: A Comparative Study" dated May 1975. The thesis is also printed (under the same title and date) as "Joint Highway Research Project Report 75-11. Funds for the study were supplied by FHWA and ISHC through JHRP. Personnel from the Division of Materials and Tests, ISHC were most helpful throughout the study.

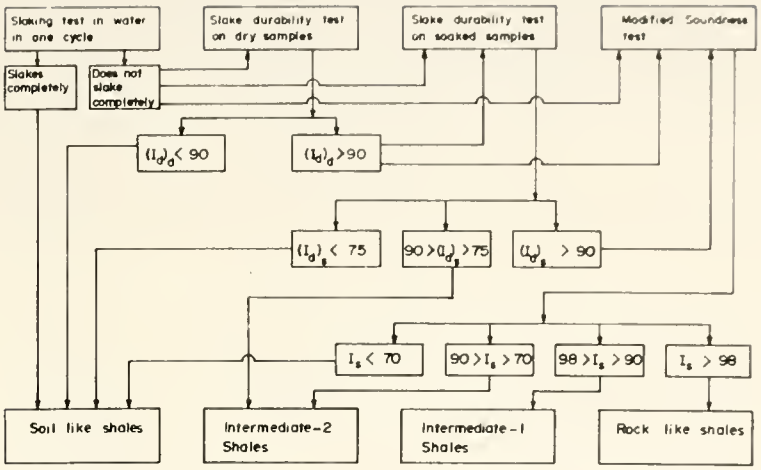

Figure 1 Classification of Shales for Embankment Construction (Deo, 1972)

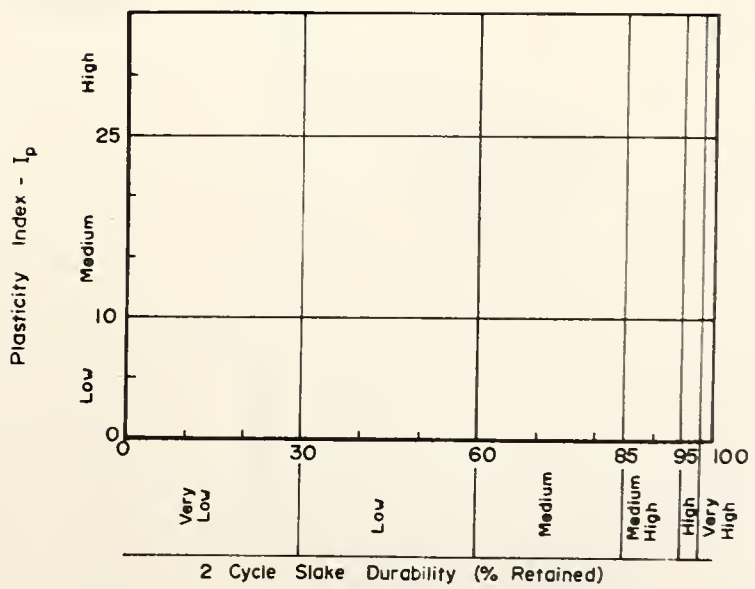

Figure 2 Durability - Plasticity Classification for Shales and Other Argillaceous Rocks (Gamble, 1971)

Rate of Slaking: $\Delta I_L = I_{L_f} - I_{L_o}$		Amount of Slaking $w_S = w_L$				
		very low VL $w_L < 20$	low L $20 < w_L < 50$	medium M $50 < w_L < 90$	high H $90 < w_L < 140$	very high VH $w_L > 140$
	slow S $\Delta I_L < 0.75$	VL S	L S	M S	H S	VH S
	fast F $0.75 < I_L < 1.25$	VL F	L F	M F	H F	VH F
	very fast VF ΔI_L 1.25	VL VF	L VF	M VF	H VF	VH VF

* 2 hours of water immersion

Figure 3 Classification in Terms of Slaking Characteristics (Morgenstern and Eigenbrod, 1974)

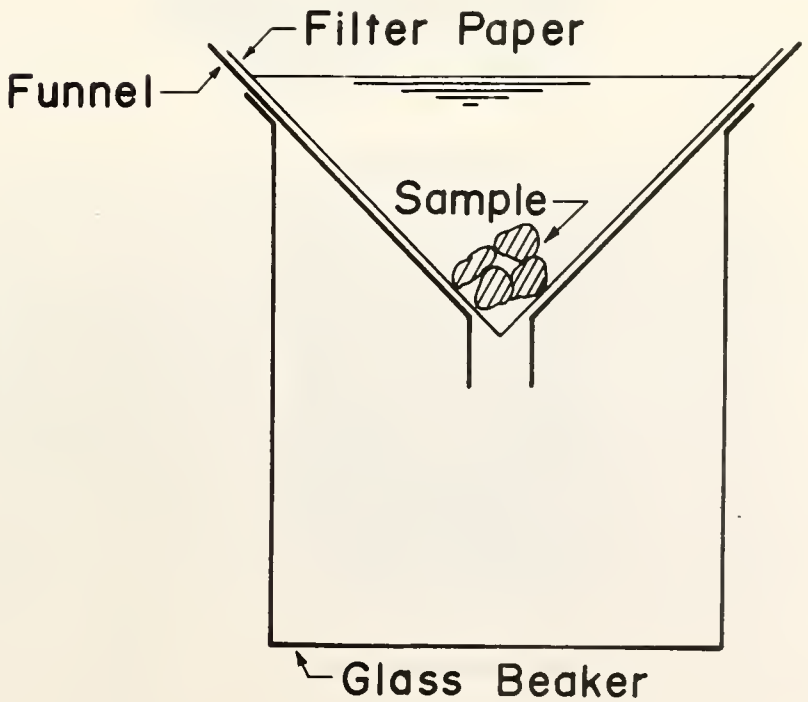

Figure 4 Set-Up for Rate of Slaking Test (Eigenbrod, 1972)

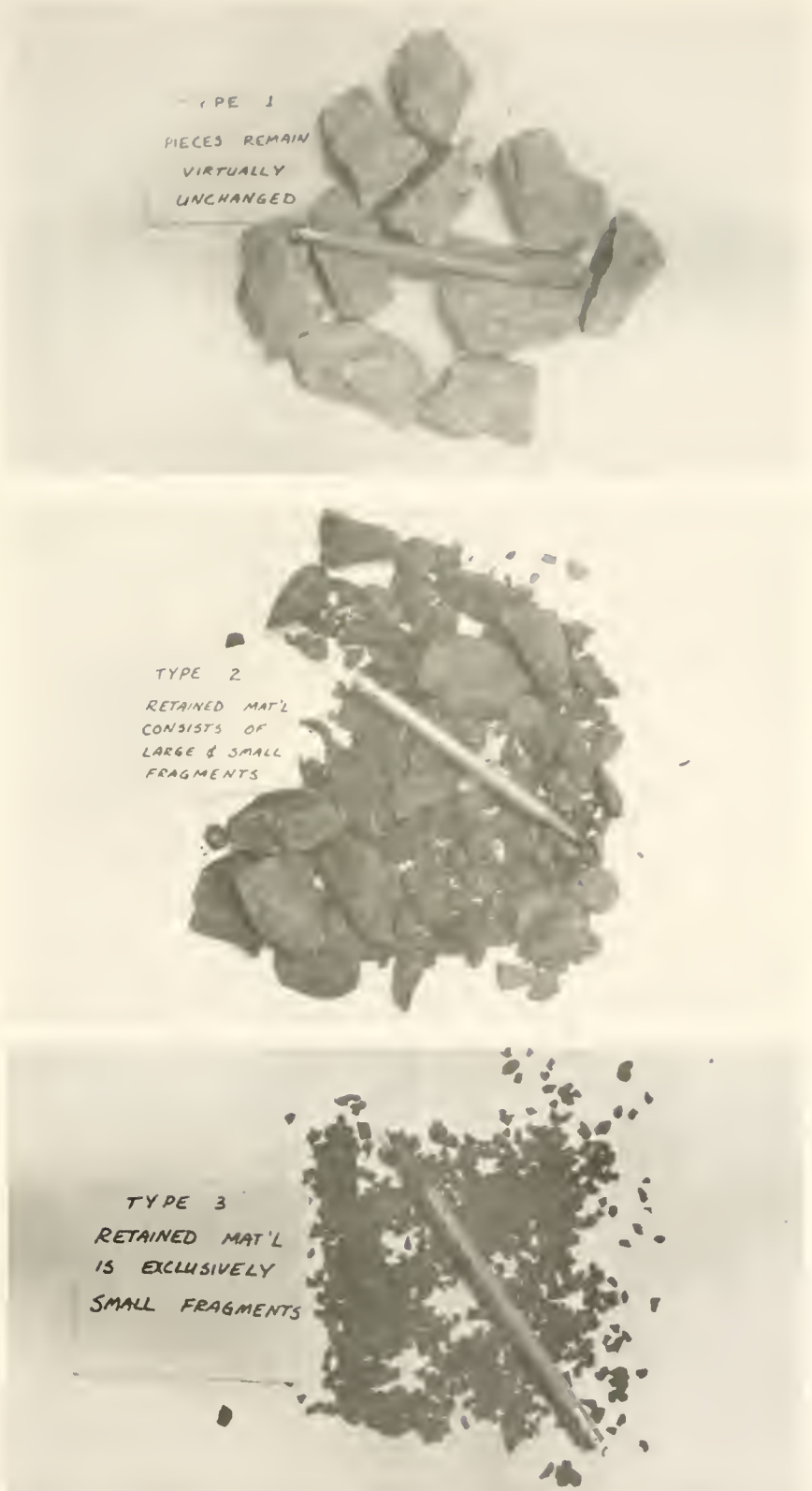

Figure 5. Material Type Classification for Slake Durability Test.

Table 1 Results for Tests from Deo's Classification System 4 (1972)

Shale	Slake Index S. I.	Modified Soundness Index I_s	Slake Durability Index					
			200 Revolutions			500 Revolutions		Material Type
			$(I_d)_d$	$(I_d)^*_d$	$(I_d)_s$	$(I_d)_d$	$(I_d)_s$	
1	99.1	0 (2 cycles)	28.6	9.8	19.2	23.3	21.0	3
2	0.14	99.6	99.6	99.3	99.6	99.7	99.2	1
3	28.2	0 (5 cycles)	90.1	72.2	74.8	79.8	56.8	2
4	42.3	0 (3 cycles)	79.7	53.5	56.6	58.4	40.3	2
5	97.8	0 (2 cycles)	80.1	48.6	16.6	28.4	7.7	3
6	0.08	99.7	98.8	98.3	98.2	97.8	97.6	1

* Values for 2nd cycle of 200 revolutions

Table 2 Shales Classified by Deo (1972), Gamble (1971), and Morgenstern and Eigenbrod (1974) Methods.

Shale	CLASSIFICATION SYSTEM				
	Deo	Gamble		Morgenstern and Eigenbrod	
		Durability	Plasticity	Rate of Slaking	Amount of Slaking
1	Soil-like	Very Low	Medium	Very Fast	Low
2	Rock-like	Very High	Low	Slow	Low
3	Soil-like	Medium	Medium	Slow	Low
4	Soil-like	Low	Medium	Slow	Low
5	Soil-like	Low	Medium	Fast	Low
6	Rock-like	Very High	Low	Fast	Low

Table 3 Results for Tests from Gambie's (1971) Classification System

Shale	Slake Durability Test	Attergerb Limits*			Unified Soil Classification
	$(I_d)_{d,200,2nd\ cycle}$	W_L	W_p	I_p	
1	9.6	42.3	27.3	15.0	ML or OL
2	99.3	34.0	28.4	5.6	ML or OL
3	72.2	36.9	21.2	15.7	CL
4	53.5	40.6	19.4	21.2	CL
5	48.6	40.6	22.2	18.4	CL
6	98.3	26.5	21.0	5.5	CL - ML

* Determined by ASTM D423-66 and D424-59.

Table 4 Results for Tests from Morgenstern and Eigenbrod's Classification Syatem (1974)

Shale	w	W_L	W_p	I_p	I_L	Δw	ΔI_L
1	12.68	42.3	27.3	15.0	-0.99	37.11	2.47
2	0.90	34.0	28.4	5.6	-4.94	0.24	0.04
3	6.30	36.9	21.2	15.7	-0.97	6.25	0.40
4	5.40	40.6	19.4	21.2	-0.65	10.50	0.51
5	10.70	40.6	22.2	18.4	-0.71	19.03	1.03
6	6.80	26.5	21.0	5.5	-3.18	4.85	0.91

Table 5 Results for Comparison of Preparation Effects on Atterberg Limits of Shale.

Shale	ASTM D421-58			Air dried			Blenderized		
	w_L	w_p	I_p	w_L	w_p	I_p	W_L	w_p	I_p
1	42.3	27.3	15.0	44.2	28.8	15.4	49.7	28.2	21.5
3	36.9	21.2	15.7	38.3	21.6	16.7	38.6	23.4	15.2
4	40.6	19.4	21.2	38.0	19.8	18.2	53.3	25.0	28.3
5	40.6	22.2	18.4	33.7	21.2	12.5	44.8	23.8	21.0

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